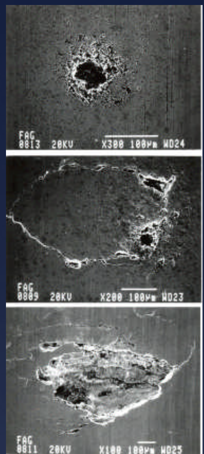
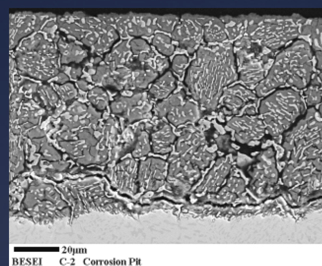
Measurement and Assessment of Bearing Degradation in Ester-Based Lubricant Systems





Darryl P. Butt
Department of Materials Science and Engineering
Boise State University, Boise, ID

Contributors:
Mike Hurley, Cole Smith, Brian Marx (now with CTC), Matt Luke (joining NR), Brandon Christoferson (now with URS), Kerry Allahar (now with NDSU), Bill Knowlton, Patrick Price

Herb Chin, Bill Ogden, Gene Danko (Pratt & Whitney)
Balky Nair (Emisense Inc.)

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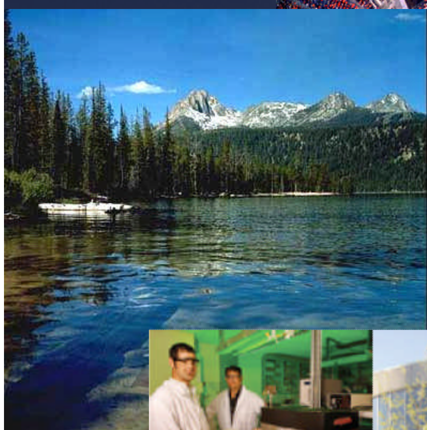
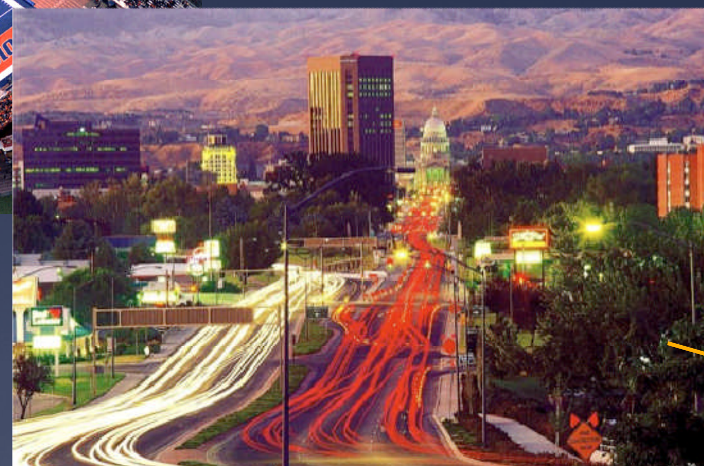
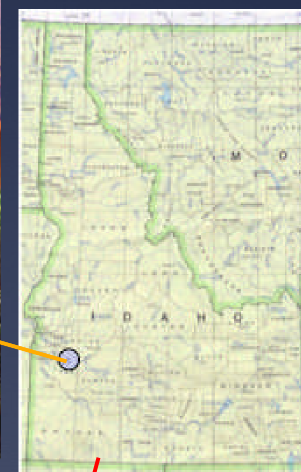
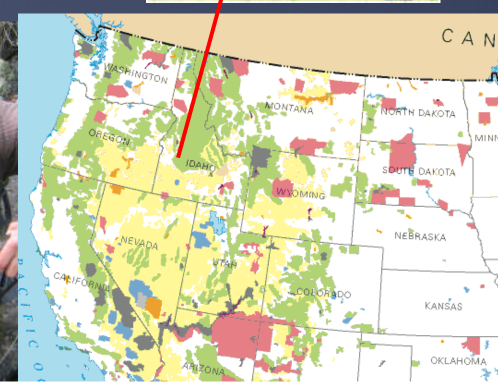








19,500 Students at BSU
College of Engineering 11 Years Old
Ranked #12 by U.S. News and World Report

Materials Science and Engineering 4 Years Old
First ABET Accredited MSE Program in Idaho
100+ Students
90%+ Undergrads Doing Paid Research, Including Corrosion

Project Overview

Oil Issues
- Additive Effects
- Seawater Contamination
- Chloride Concentrations
- Oxidation/Degradation

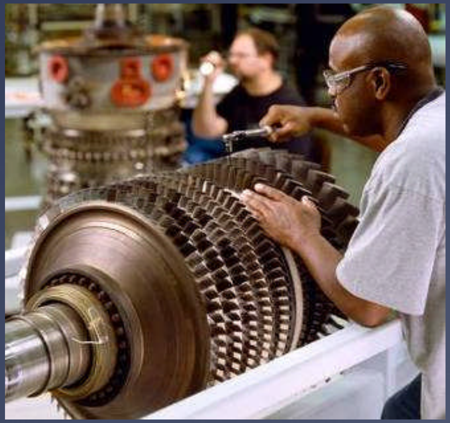
Corrosion Issues in Oils
- Alloy Microstructure
- Seawater Content (Emulsions)
- Chloride Concentrations
- Effect of Temperature

Materials Issues
- Sensor Circuitry
- Sensor Body
- Sensor Substrate
- Joining Brazes

Oil/Water Electrochemical Properties

Corrosion Rates, Mechanisms, Pitting of Bearing Alloys

Sensor Optimization: Monitor Oil Quality/Corrosion



Sensor Construction

Sensor Testing

Deployment of Sensor to Application

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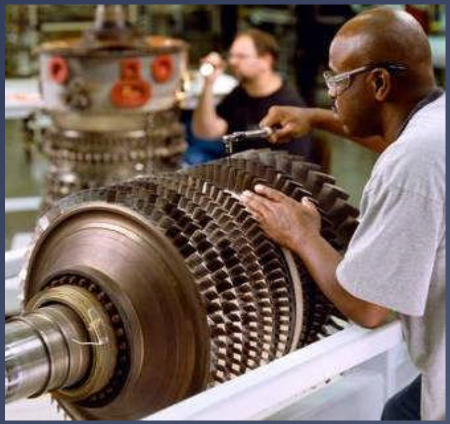


Sensor Testing

Deployment of Sensor to Application

Bearing Materials and Oils

Bearing Steels

Material	C (Case)	Cr	V	Mo	Si	Mn	C	Co	Ni	Fe
M50	--	4	1	4.25	0.3	0.3	0.8	--	--	Bal.
P675	~2%	13	0.6	1.8	0.4	0.65	0.07	5.4	2.6	Bal.

Compositions in wt%

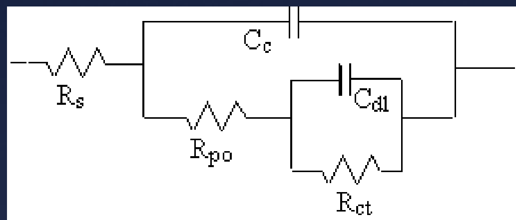
Lubricant-Water Systems

Oils
BP 2389
BP Alo 16360
BP Alo 16561
Chevron 10W 40 oil
Chevron 15 W 40
Chevron 5W-20 oil
Delo 400
GTX 520
Hatcol 3212
Hatcol 3214
Hatcol 4213
Jet oil 254
Mobiel 10W 40 oil
Mobile 5W 20 oil
Pennziol 10W 40 oil
Pennziol SW 20
Pennzoil 5 W 30
Turbo 1294
Turbo 2380
Turbo 2389
Valvoline 410
Valvoline 520

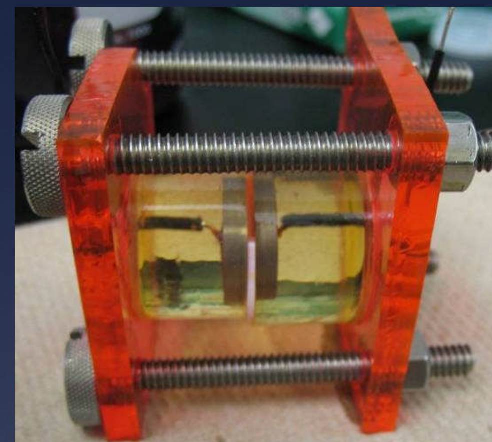
Oil	Water, ppm	$[Cl^-]$ (Moles)
BP 16360 Valvoline 520	200-8000	0.001-1

Polyol esters	Anti-oxidants	Anti-wear / Extreme Pressure	Corrosion Inhibitors	Rust Inhibitors	Anti-Foam Agents
94-97%	2-4%	1-3%	<0.5%	<0.5%	ppm level

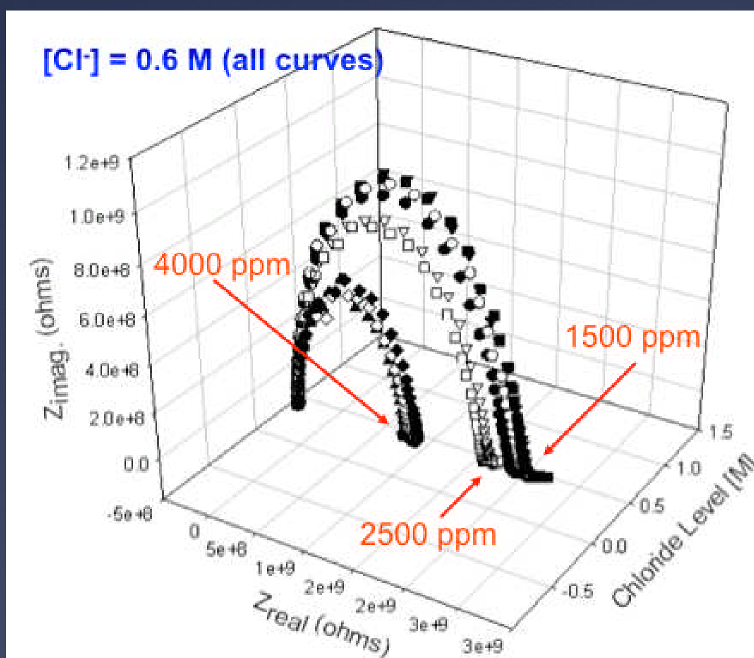
EIS Necessary in High Impedance Solutions



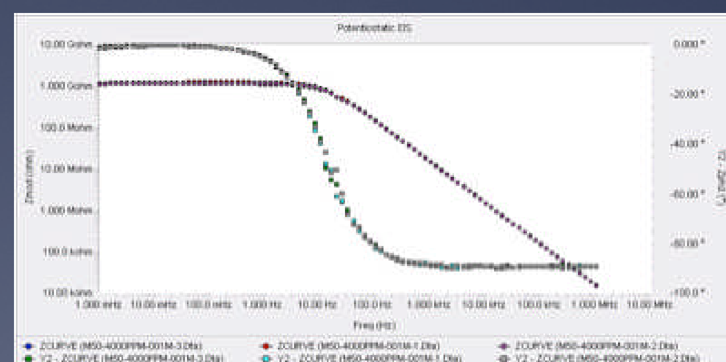
Unlike DC, AC E-chem can discern individual circuit components



BSU Cell



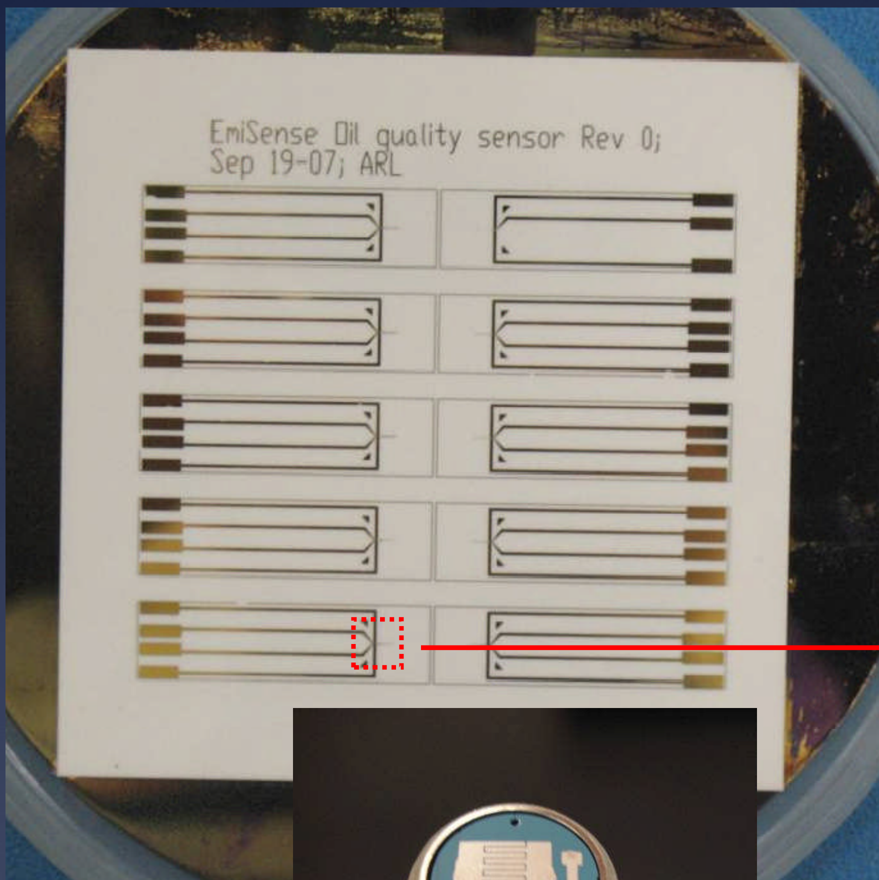
- 1,000,000 Hz – 0.001 Hz
- 10 mV AC
- 300s delay
- Polished to 1 µm
- 1 mm electrode spacing using Teflon sheet

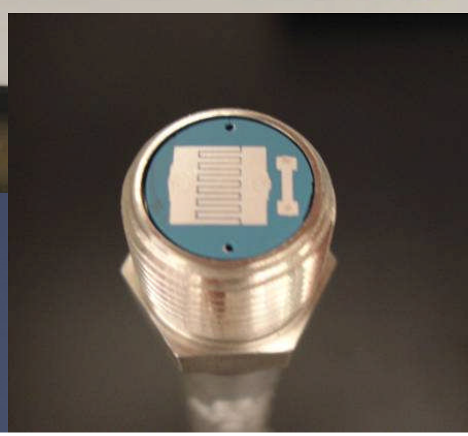


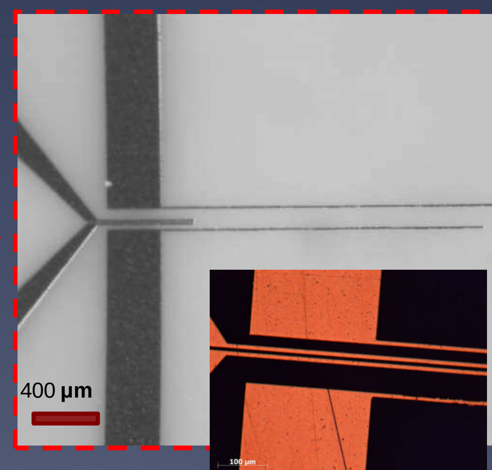
*K. Allahar, M. Orazem, D. P. Butt, Electrochimica Acta, **2006**, *51*, 1497-1504.

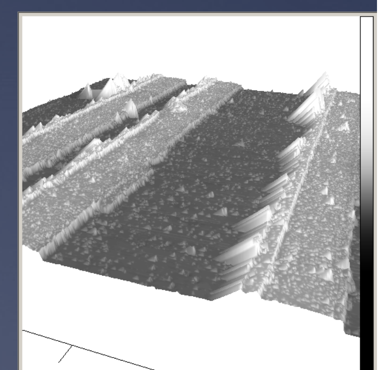
Oil Sensor Structures

Deposited Sensors

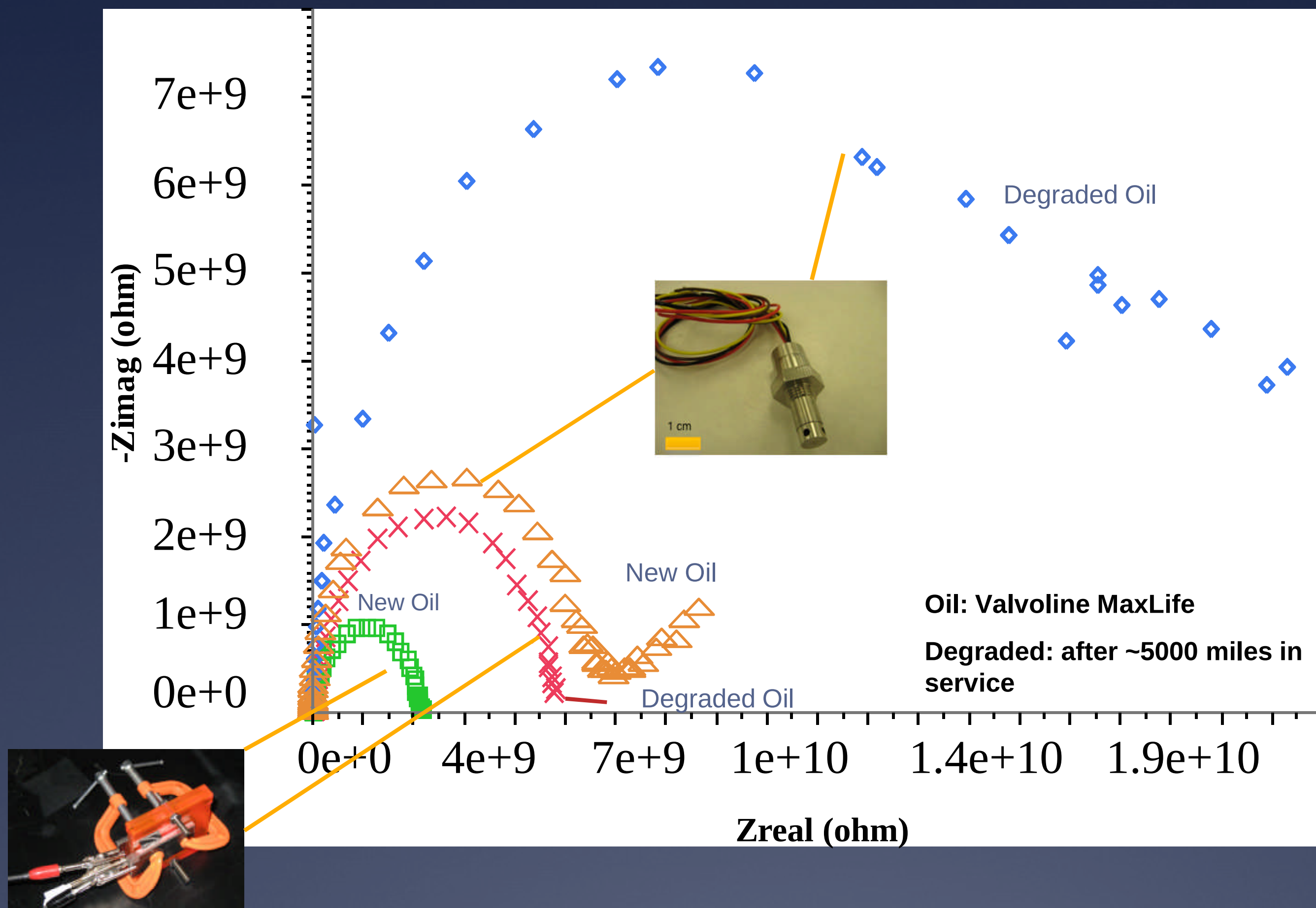








Influence of Oil Degradation on Impedance: Sensor vs Bulk Electrode

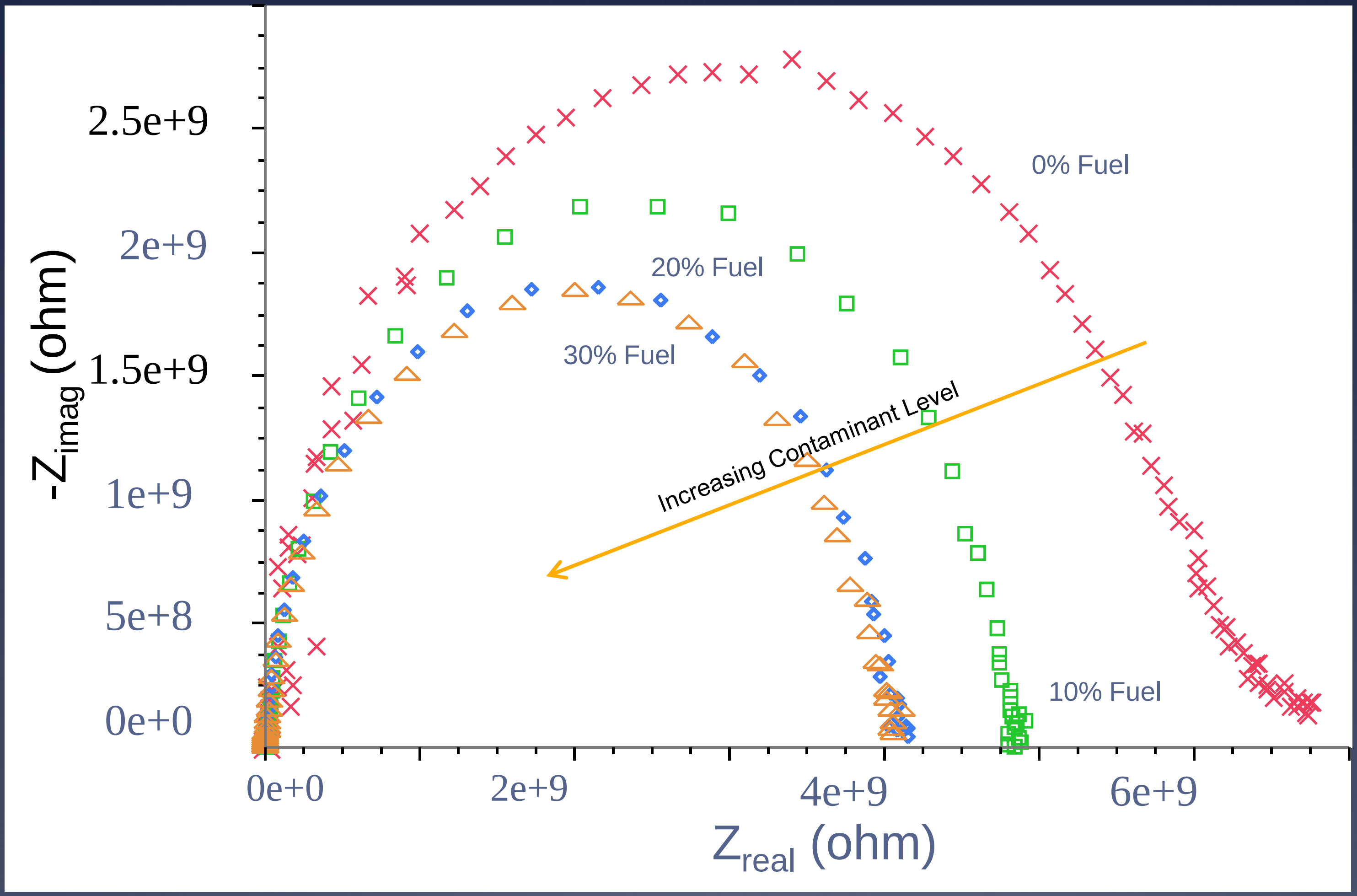


$R_{\Omega}=\rho_{sol.}\boxed{(L/A)}$

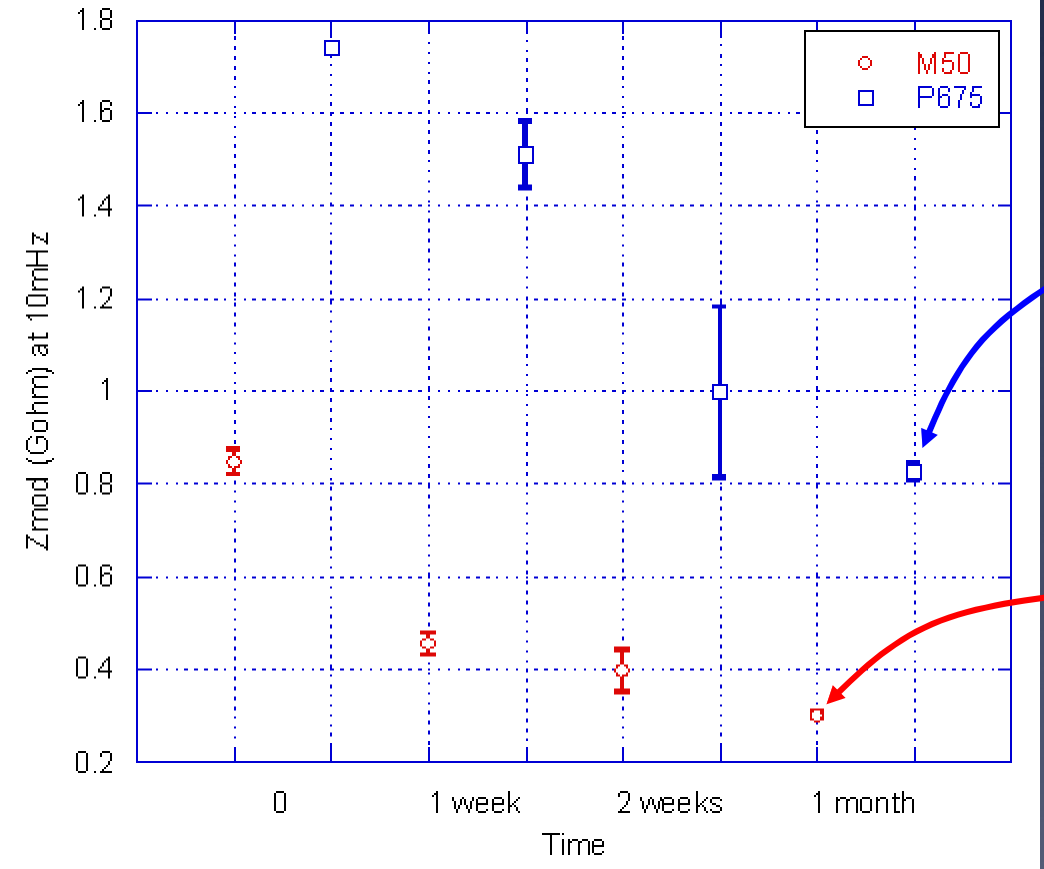
= 0.8 bulk electrode

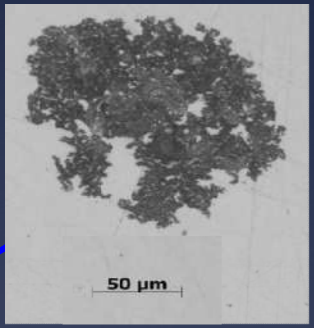
= 4.75 Emisense electrode

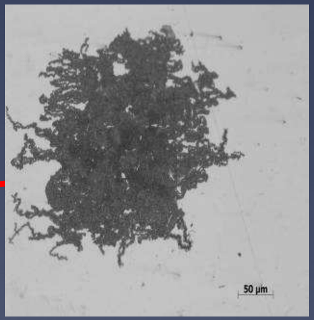
Sensing Diesel Fuel Contamination of Oil



Impedance Decreases with Immersion Time





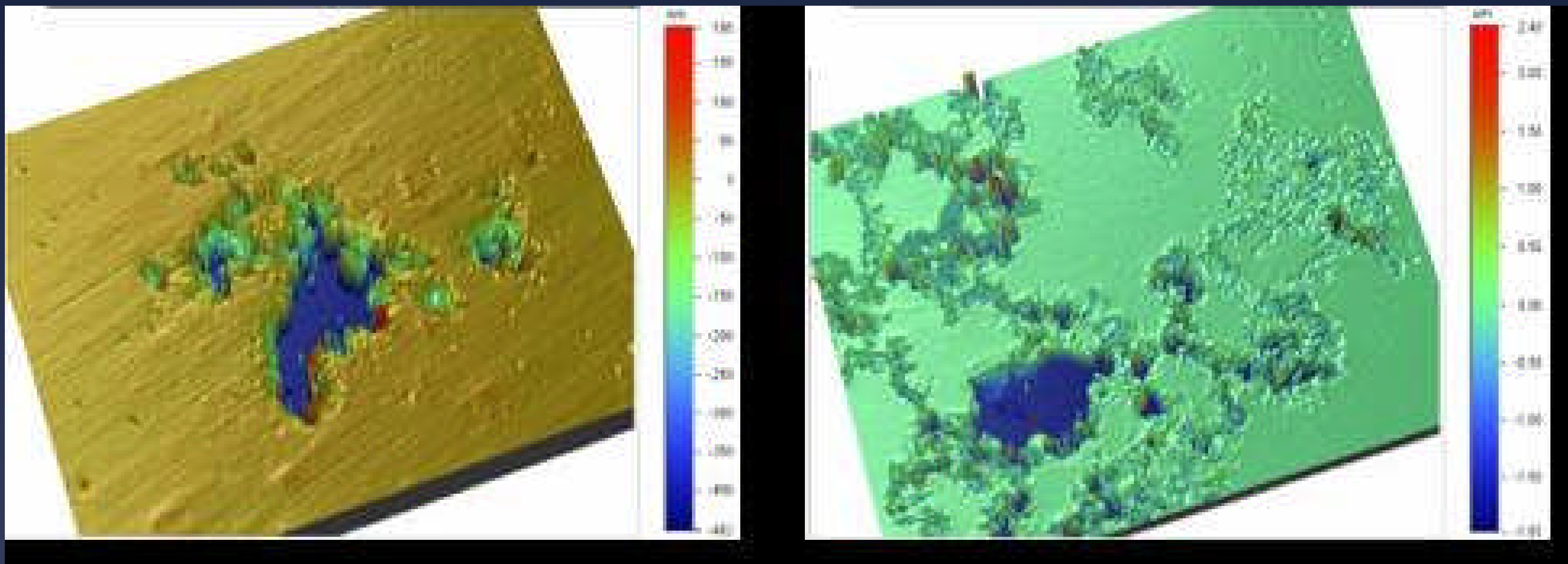


Conditions:

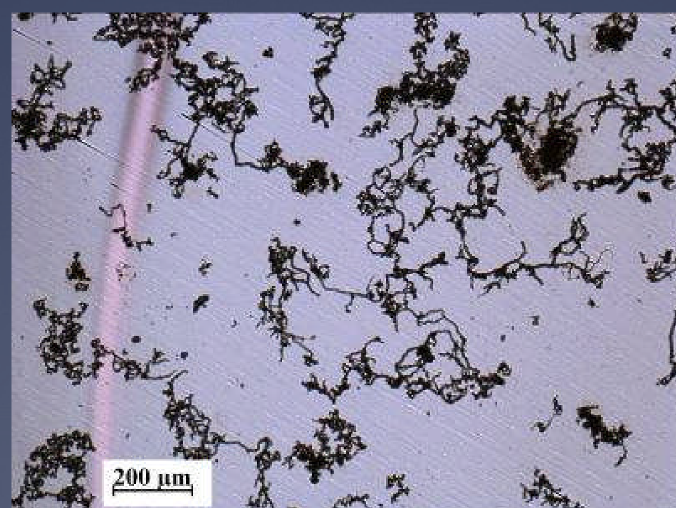
- Ambient aeration
- 2500 ppm 0.6 M NaCl
- Average of 3 runs

Filiform Corosion?

AFM



Optical



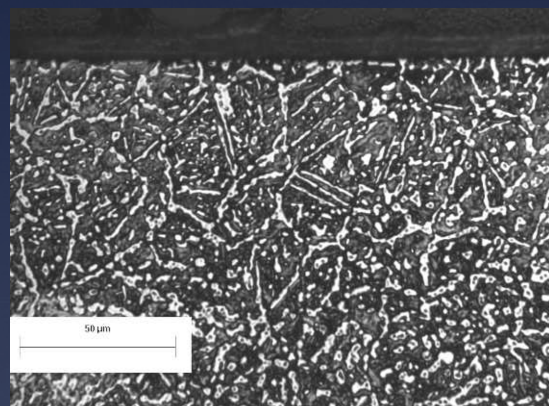
M50

Microstructure, Emulsion Characteristics vs. Corrosion

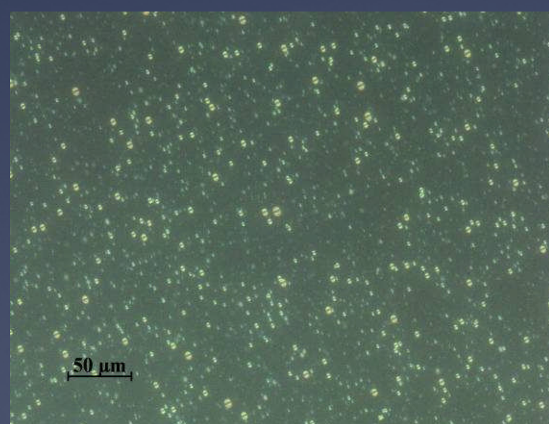
Objective:

Link alloy microstructure with corrosion behavior

Beginning Microstructure



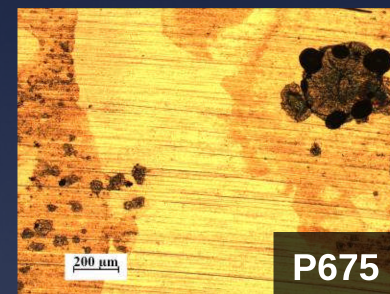
Seawater/Oil Emulsion

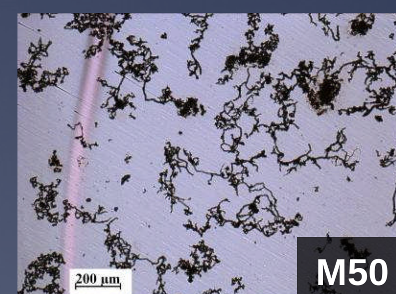


Influence of Microstructure

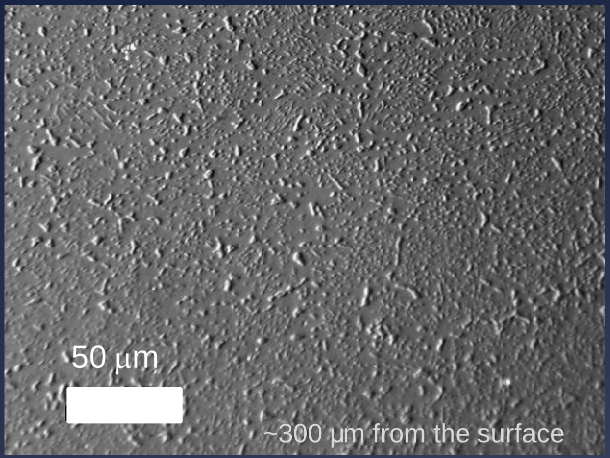
Influence of Seawater/Oil Emulsions

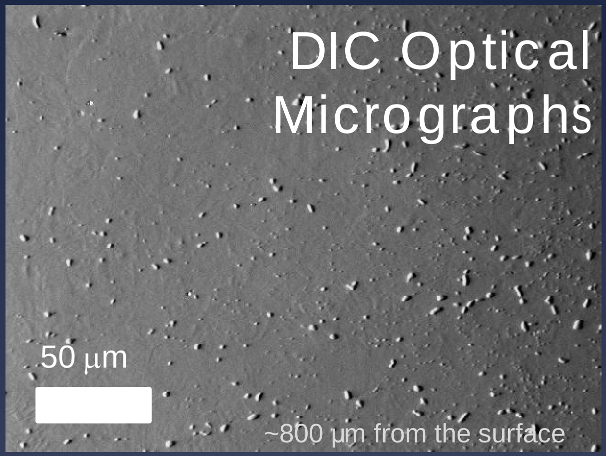
Types of Corrosion Damage Observed





Carbide Distribution in P675





Differential **I**nterference **C**ontrast

False topography resolves carbides from phase difference in reflected light

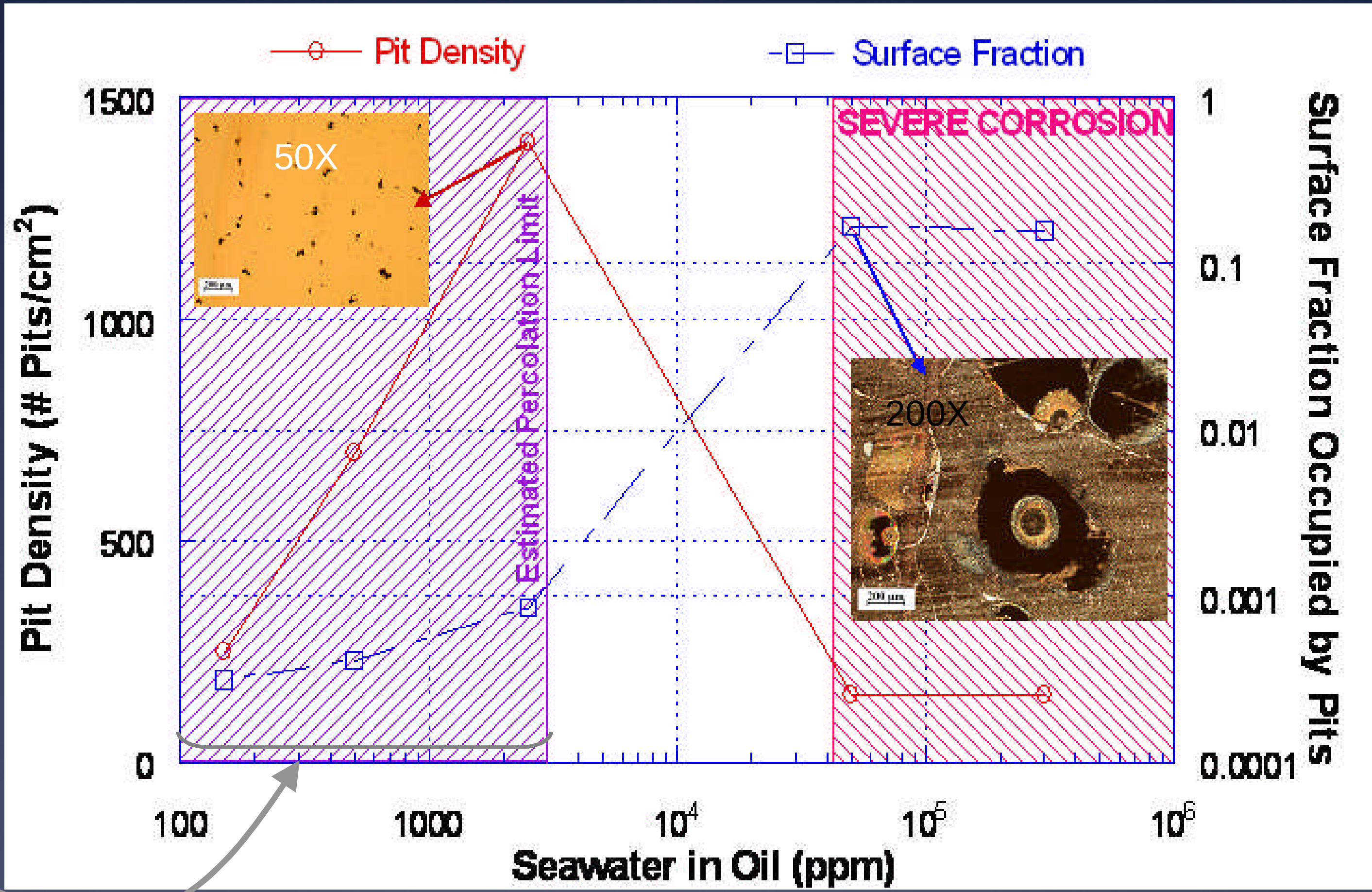
Pit Density and Area Fraction vs. Contamination Level

Below 3000 ppm Seawater content:

Pit density increases with water content

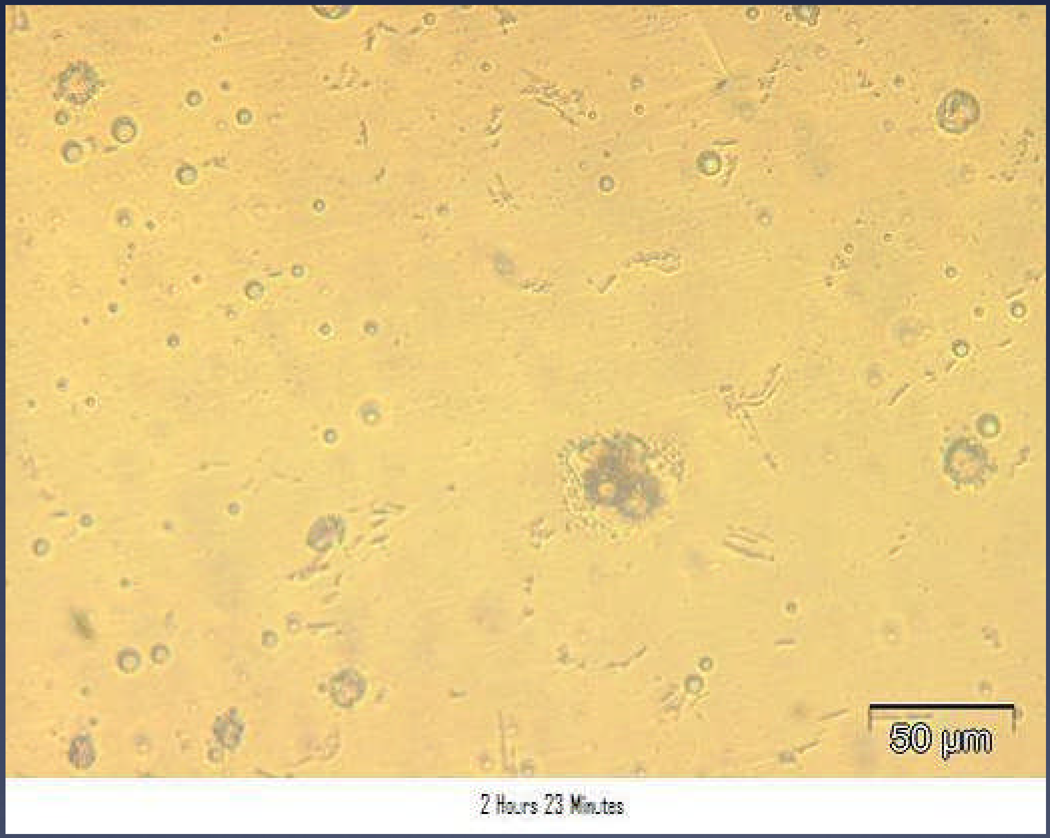
Surface fraction of attack increases but less rapidly than pit new pit formation

Propagation seems to occur by pit clustering adjacent to active corrosion sites and coalescence existing localized attack



Pitting Below An Ester-Water Emulsion

M50
8000 ppm H_2O
1 M NaCl
24 hour series



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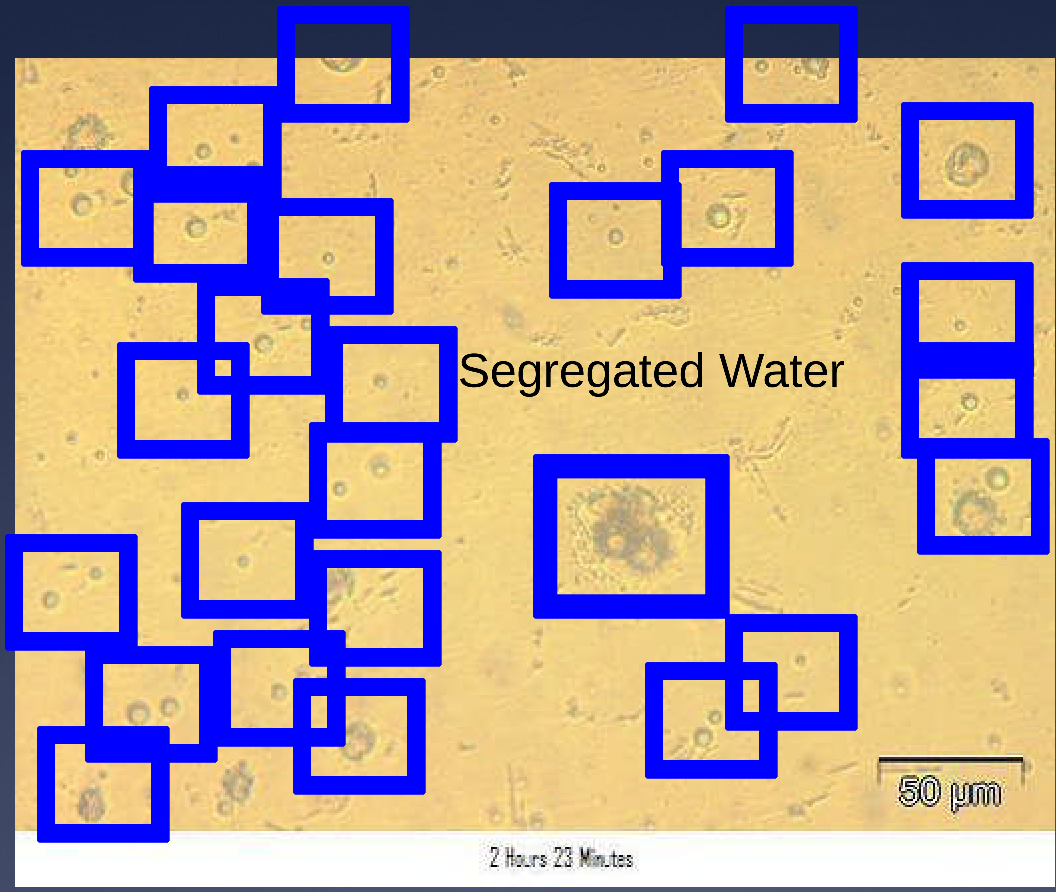

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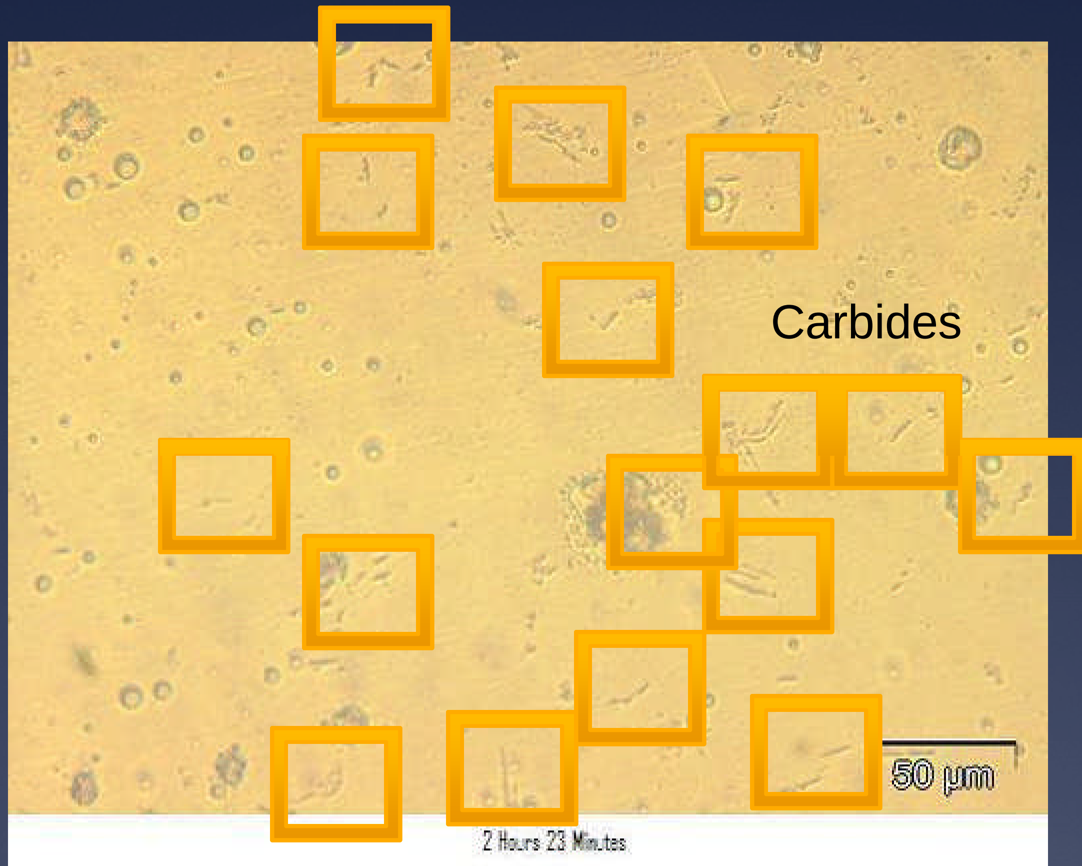

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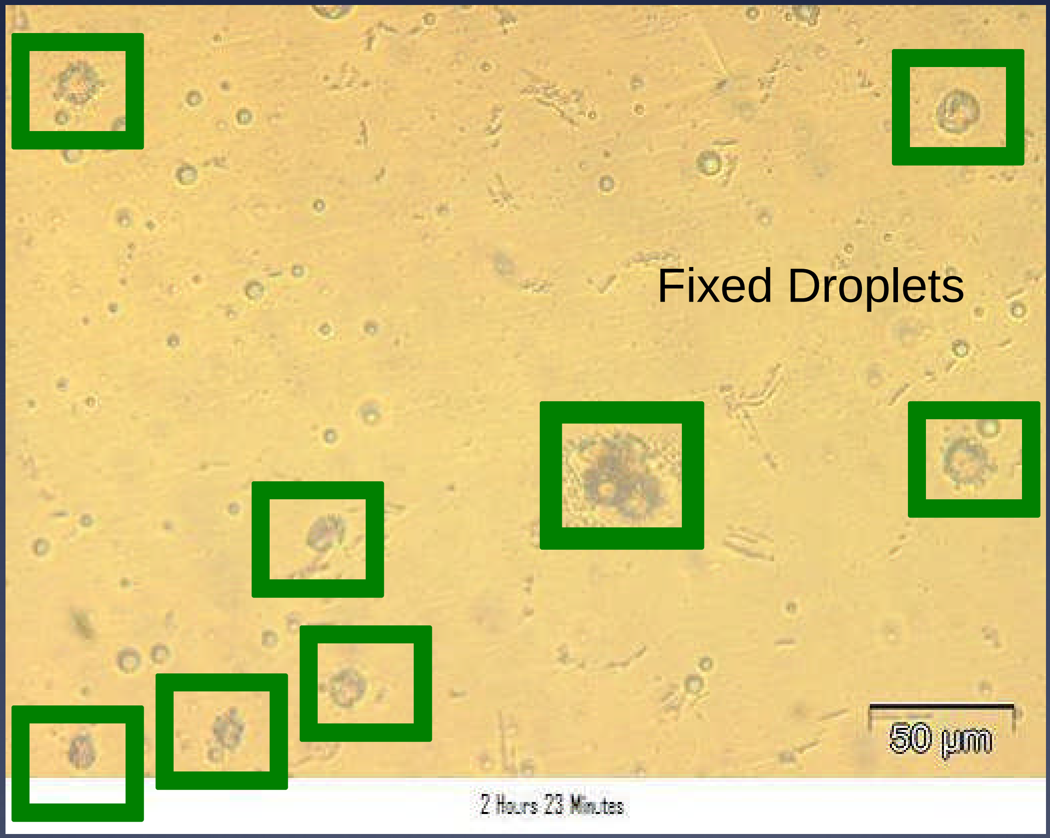

Carbides observed under fixed droplets

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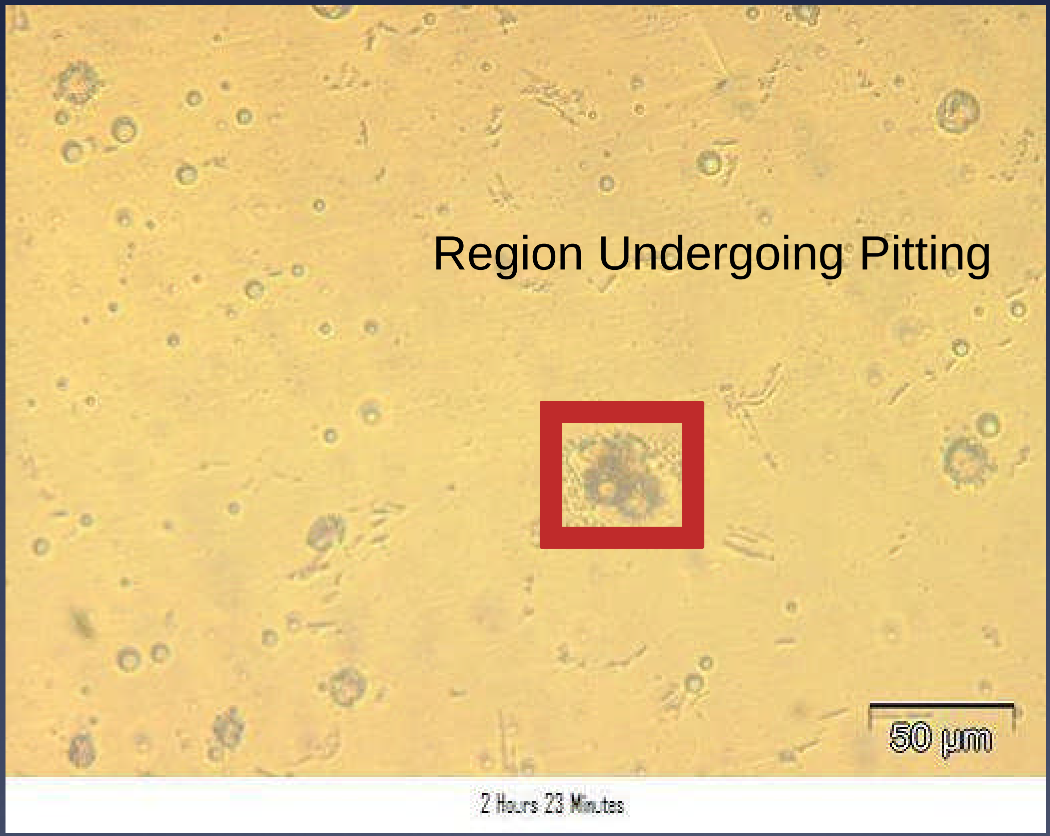

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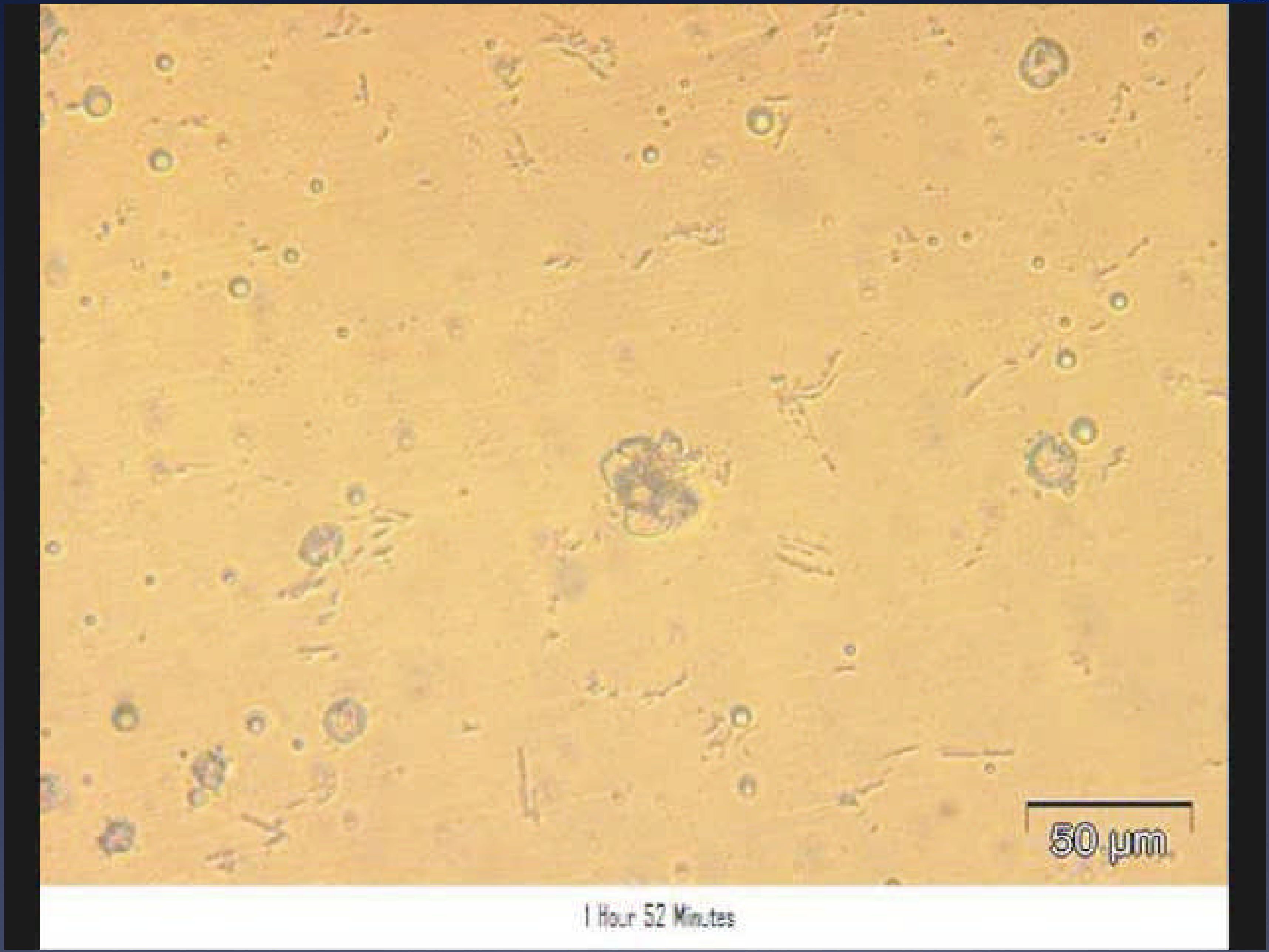
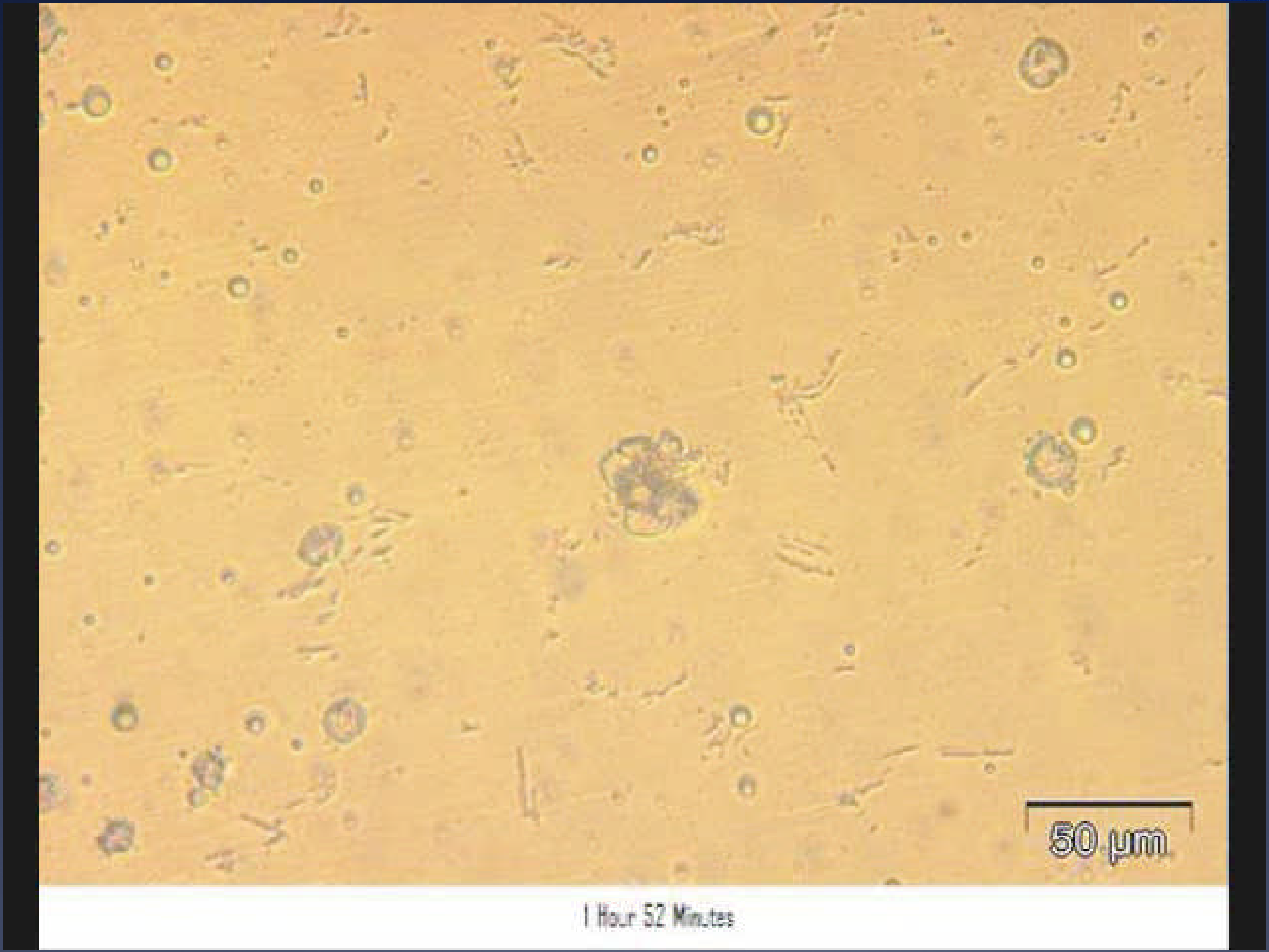


Time Lapse Photography-OFF



Time Lapse Photography-ON

Summary of Observations and "Speculations"

- **M50 is susceptible to general corrosion and pitting initiating around carbides and grain boundaries**
- **P675 is much more resistant to general corrosion, but susceptible to localized attack due to larger surface carbides**
- **Localized attack can have a "filiform" appearance**
- **Oxygen availability is a likely limiting factor, regardless of oil contamination level**
- **Corrosion is possible over a wide range of salt and water contamination levels in oil, but severity (measured by pit depth) is greatest above the solubility limit for water**
- **Pit density increases with [H_2O] with [Cl^-] being a secondary effect**
- **Robust sensors developed for monitoring corrosion and oil quality can detect at, low *f*, statistically significant changes in...**
  - **H_2O contamination, oil degradation, impedance response of materials, immersion time**

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- Pitting has been observed beneath immersion water droplets
- Droplets may adhere or cluster around carbides--these droplets tend to grow at the expense of mobile emulsion droplets
- “Free” droplets may migrate electrophoretically toward other droplets (i.e., droplet diffusion is not Brownian)
- Near rapidly forming pits, nanometer scale emulsions appear, possibly by spinodal decomposition
- Dissolved water may diffuse towards microgalvanic potential associated with corrosion beneath immersion droplet
- Some evidence that salt condenses out near corrosion pit
- Systems at rest likely to corrode more severely than systems in operation

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End

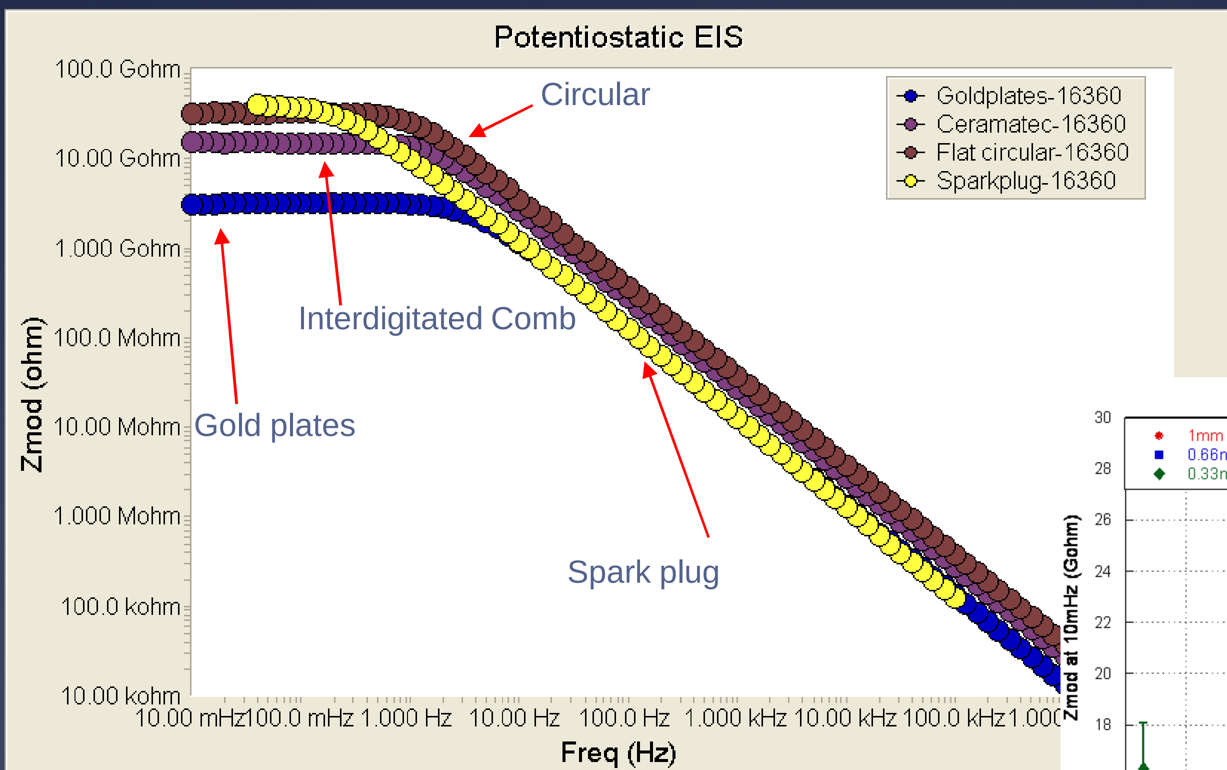
Boise State University

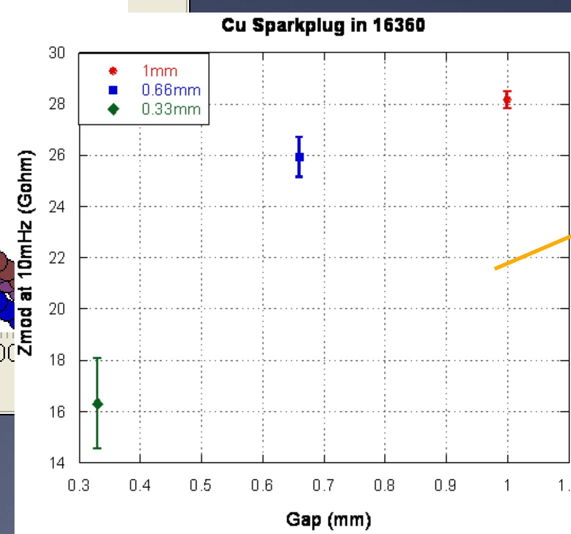
Department of Materials Science and Engineering

Sensor Geometry Effects

Multiple “capacitor type” configurations tested in 16360 Oil

- – Maximize Area/Separation distance
- – Minimize real estate to allow for multiple sensors

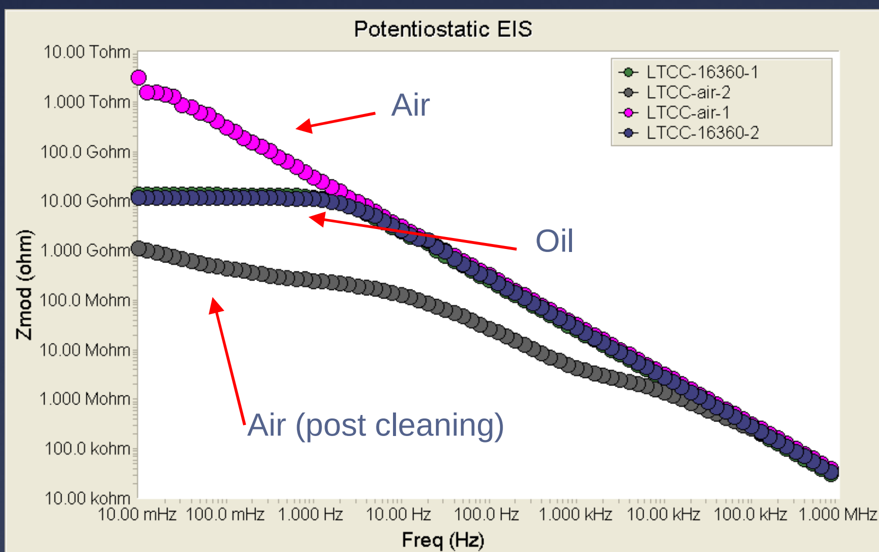


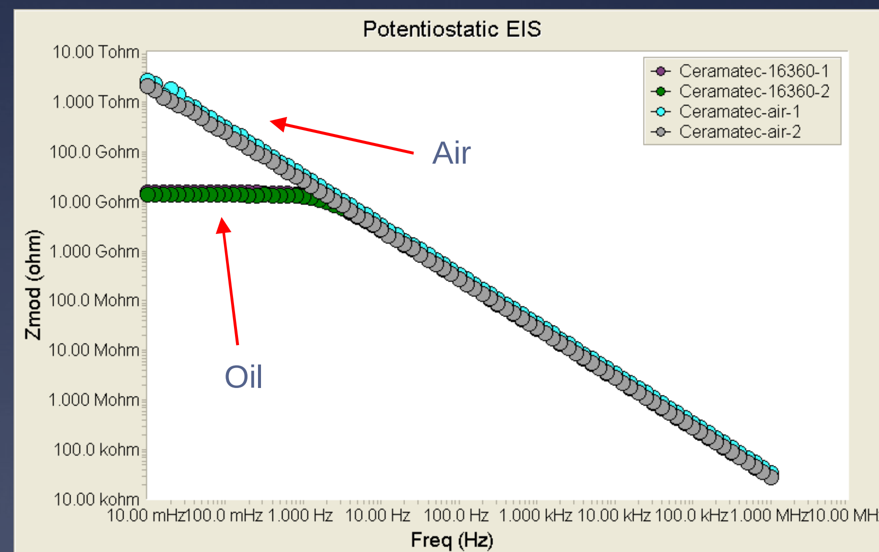


Sensor Materials Selection

LTCC vs. Alumina

1. Air
2. Oil
3. Clean, air again
4. Oil again





Polymer Seals Comparison